Classification of Urinary Dielectric Properties for Diabetes and Kidney Disease using Support Vector Machine*

Peck Shen Mun, Hua Nong Ting
Department of Biomedical Engineering
University of Malaya
Kuala Lumpur, Malaysia
tinghn@um.edu.my

Mirhassani Seyed Mostafa
Department of Electrical Engineering
University of Shahrood
Shahrood, Iran

***Abstract*—This paper classifies the urinary dielectric properties of subjects with diabetes mellitus (DM), chronic kidney disease (CKD), and normal subjects at microwave frequency from 1 GHz to 50 GHz using support vector machine (SVM). The dielectric properties measurements were conducted using open-ended coaxial probe at room temperature (25°C), 30°C and human body temperature (37°C). The highest classification accuracy was achieved at 88.72% to distinguish diabetic subjects from normal. The urinary dielectric behavior was found optimal at 30°C. The highest accuracy was achieved at 64.50% for three-group classification.**

Keywords—dielectric properties; urine; temperature; support vector machine

I. INTRODUCTION

Urinary measurement is an essential non-invasive approach for disease diagnosis. Measurement of urinary glucose is used to test for diabetes. Meanwhile, persistent presence of protein in urine is a presentation of chronic kidney disease (CKD) due to progressive decline of renal function. However, urinary test strips that use color charts to determine glycosuria or proteinuria variability are less accurate compared to those that use numerical readouts [1]. Biomaterial dependency of dielectric changes in aqueous solutions and biological fluids were determined. Studies showed the effects of temperature and frequency for the changes of the dielectric properties in glucose solution [2], [3] and protein solution [4], [5]. The presence of urinary glucose showed different dielectric properties of urine [6], [7]. Reference [8] found that the urinary dielectric properties changed with glycosuria level and temperature at frequencies up to 50 GHz. The changes of urinary dielectric properties to detect different proteinuria level were also investigated [9].

Dielectric properties measurement offers the potential to determine variability of urinary glucose or protein as a simple and non-destructive manner. However, the accuracy of the determination should be investigated. Data classification has been applied as the most intensive studied in statistics and decision science especially for disease diagnosis. Applications of support vector machine (SVM) classification for diabetes [10], [11], kidney disease [12]-[15], and cancers [16]-[20] had validated the capable performance of support vector machine classifier. Reference [17] considered the priority of dielectric properties of breast tissue in classification has increased the classification probability value between a tumor and normal breast tissue.

In this study, we aim to classify the urinary dielectric properties of subject groups, which involved subjects with diabetes mellitus (DM), subjects with chronic kidney disease (CKD), and normal subjects at room temperature (25°C), 30°C and body temperature (37°C), respectively, between microwave frequency ranging from 1 GHz to 50 GHz. SVM-based classification was applied to classify urinary dielectric properties among subject groups and the effect of temperature in classification accuracy was determined.

II. MATERIALS AND METHODS

This study involved a total of 102 subjects with type II DM, CKD (n=130) and 97 healthy subjects, respectively. 50ml random spot of mid-stream urine samples were collected from each subject. Medical ethics approval was obtained from the Institutional Ethics Review Committee, UMMC, Malaysia before carrying out the study. All subjects were given of informed consent before the urine collection. Fresh urine samples were collected and stored in refrigerator at temperature of 4 °C before measurement within 4 hours. No preservatives were added to the urine upon collection.

Open-ended coaxial slim probe with computer controlled network analyzer (PNA Agilent E8364C)) with frequencies ranging from 1 GHz to 50 GHz was used to measure the urinary dielectric properties in terms of dielectric constant (ε') and loss factor (ε") as shown in Fig. 1. The network analyzer was calibrated with references for air, short circuit and deionized water before the measurements took place. Electronic-calibration (E-Cal) was used as the standard for refresh calibration.

This work was supported in by the University of Malaya under Postgraduate Research Grant PG036-2013A.

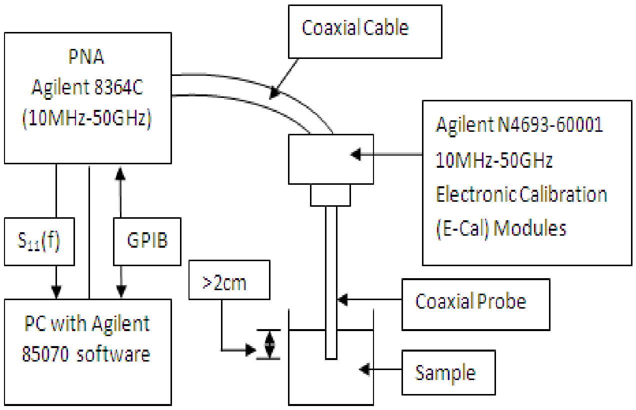

Fig. 1. Schematics representation of the measurement set up. Agilent E8364C personal network analyzer (PNA; 10 MHz-50 GHz) operated with Agilent 85070 software through Agilent 82357A GPIB interface was used to measure dielectric properties of samples. Reflection coefficient (S_{11}) measured by PNA was converted to dielectric properties of the sample by the program software. E-Cal module provided the standard refresh calibration for measurement.

Before measurements were conducted, the urine samples were heated to room temperature (25°C) using water bath with a precision of ± 0.1°C and the samples were gently stirred. The dielectric probe was cleaned and sterilized using alcohol wipe before each measurement. Experiments were repeated by heating the urine sample to 30°C and 37°C respectively. Three measurements were recorded at each temperature.

SVM-based classification of urinary dielectric properties was performed using the LIBSVM tool in Matlab software (version 2010a). A total of 50 variables were used, which were the values of the urinary dielectric properties at the frequency point from 1 GHz to 50 GHz. Classification was accomplished based on 3-fold cross validation method. Radial basic function (RBF) kernel function as below was applied:

$$K(x,x_i) = \exp(-\gamma \|x - x_i\|^2) \quad (1)$$

Where input samples, $X = \{x_1, x_2, \ldots x_i\}$ and parameter, γ ∊ [0.1, 10] were tested in the system to determine the optimal classification accuracy. Classification models were generated based on the respective urinary dielectric constant and loss factor at 25°C, 30°C and 37°C, respectively. The classifiers were applied to the database to perform classification to the subjects based on different urinary dielectric properties.

III. RESULTS

The classifications were performed using the database of urinary dielectric properties with 50 variables. RBF kernel function with γ = 0.5 was found to show optimal performance in classification. Fig. 2 shows the architecture of SVM that construct a decision disease classification for non-linear dielectric properties input space.

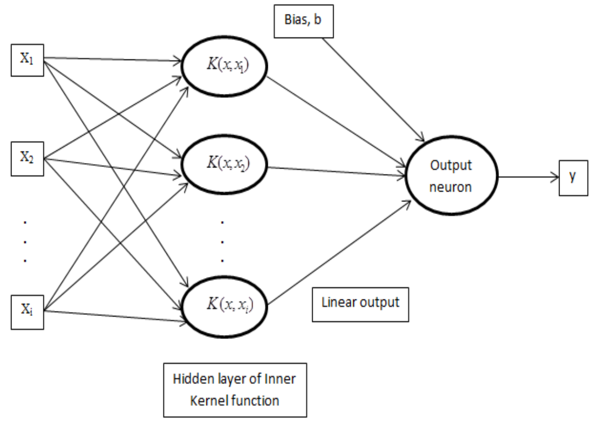

Fig. 2. Architecture of SVM. The hidden layer of RBF inner Kernel function, as in (1) construct classification decision surface for non-linear dielectric properties inputs space.

Table 1 and Table 2 show the sensitivity, specificity and classification accuracy of the urinary dielectric properties between DM and normal subjects at 25°C, 30°C and 37°C. Classification accuracies of urinary dielectric constant showed 84.02%, 88.72% and 82.99% for 25°C, 30°C and 37°C, respectively. Meanwhile, the accuracy was reported at 77.20%, 80.51% and 80.0% for 25°C, 30°C and 37°C, respectively using urinary loss factor. The highest classification accuracy was achieved at 30°C for both dielectric constant and loss factor. Overall, higher sensitivities and specificities were observed using urinary dielectric constant than loss factor except for 37°C.

Table 3 shows the classification accuracy of the urinary dielectric properties among DM, CKD and normal subjects at 25°C, 30°C and 37°C. Classification model showed classification accuracy of 62.14%, 63.68% and 64.50% using urinary dielectric constant in three-group classification. Urinary loss factor produced accuracy of 59.20%, 63.87% and 63.22% at 25°C, 30°C and 37°C, respectively. Overall, urinary dielectric constant showed higher classification accuracies than loss factor except for classification at 30 °C that had deviation <0.5 %.

TABLE I. SENSITIVTY, SPECIFICITY AND CLASSIFICATION ACCURACY BETWEEN DM AND NORMAL SUBJECTS USING URINARY DIELECTRIC CONSTANT AT 25°C, 30°C AND 37°C

	25°C	**30°C**	**37°C**
Sensitivity (%)	76.47	88.23	74.25
Specificity (%)	92.39	89.24	92.47
Classification Accuracy (%)	84.02	88.72	82.99

TABLE II. SENSITIVTY, SPECIFICITY AND CLASSIFICATION ACCURACY BETWEEN DM AND NORMAL SUBJECTS USING URINARY LOSS FACTOR AT 25°C, 30°C AND 37°C

	25°C	**30°C**	**37°C**
Sensitivity (%)	67.65	78.43	83.33
Specificity (%)	87.91	82.80	76.34
Classification Accuracy (%)	77.20	80.51	80.0

TABLE III. CLASSIFICATION ACCURACY OF URINARY DIELECTRIC PROPERTIES AMONG DM, CKD AND NORMAL SUBJECTS USING AT 25°C, 30°C AND 37°C

Dielectric Properties	**25°C**	**30°C**	**37°C**
ε’	62.14	63.68	64.50
ε”	59.20	63.87	63.22

IV. DISCUSSION

According to Table 1 and Table 2, the classification model produced considerably high accuracy to distinguish the respective DM subjects from normal subjects by measuring the dielectric properties of excretory urine. These findings showed an existence a unique pattern of urinary dielectric properties between normal and DM subjects at microwave frequencies from 1 GHz to 50 GHz. The presence of glucose affects the overall urinary dielectric properties [8].

Temperature effect was observed on the sensitivity, specificity and classification accuracies of urinary dielectric properties. The accuracies were varied from 3% to 6% among different temperatures subjects. We found the dielectric behavior of urine was optimal at 30 °C for classification between DM and normal subjects. Urine is a complex biological solution that consists of different chemical constituents. The randomizing agitation of molecules at certain high temperature could reduce the overall classification accuracy. The highest classification accuracy was produced at 64.50% for three-group classification. This study suggests urinary dielectric properties classification would be able to distinguish disease patients from normal based on different pathological process at optimal temperature.

REFERENCES

[1] D. E. Goldstein, R. R. Little, R. A. Lorenz, J. I. Malone, D. Nathan et al., "Tests of glycemia in diabetes," Diabetes Care, vol. 27, pp. 1761-1773, 2004.

[2] V. Meriakri, E. Chigrai, D. Kim, I. Nikitin, L. Pangonis et al., "Dielectric properties of glucose solutions in the millimetre-wave range and control of glucose content in blood," Meas. Sci. Technol., vol. 18, pp. 1-6, 2007.

[3] P. F. Smulders, M. G. Buysse, and M. D. Huang, "Dielectric properties of glucose solutions in the 0.5–67 ghz range," Microwave Opt. Technol. Lett., vol. 55, pp. 1916-1917, 2013.

[4] S. Boresch, P. Höchtl, and O. Steinhauser, "Studying the dielectric properties of a protein solution by computer simulation," The Journal of Physical Chemistry B, vol. 104, pp. 8743-8752, 2000.

[5] D. V. Matyushov, "On the theory of dielectric spectroscopy of protein solutions," J. Phys. Condens. Matter, vol. 24, pp. 325105-325120, 2012.

[6] A. Lonappan, V. Hamsakkutty, G. Bindu, J. Jacob, V. Thomas et al., "Dielectric properties of human urine at microwave frequencies," Microwave Opt. Technol. Lett., vol. 42, pp. 500-503, 2004.

[7] A. Lonappan, G. Bindu, V. Thomas, J. Jacob, C. Rajasekaran et al., "Diagnosis of diabetes mellitus using microwaves," Journal of Electromagnetic Waves and Applications, vol. 21, pp. 1393-1401, 2007.

[8] P. S. Mun, H. N. Ting, Y. B. Chong, and T. A. Ong, "Dielectric properties of glycosuria at 0.2-50 ghz using microwave spectroscopy," Journal of Electromagnetic Waves and Applications, pp. 1-15, 2015.

[9] P. S. Mun, H. N. Ting, T. A. Ong, C. M. Wong, K. H. Ng et al., "A study of dielectric properties of proteinuria between 0.2 ghz and 50 ghz," PloS one, vol. 10, p. e0130011, 2015.

[10] H. J. Ban, J. Y. Heo, K. S. Oh, and K. J. Park, "Identification of type 2 diabetes-associated combination of snps using support vector machine," BMC Genetics, vol. 11, pp. 26-36, 2010.

[11] U. Roshan, S. Chikkagoudar, Z. Wei, K. Wang, and H. Hakonarson, "Ranking causal variants and associated regions in genome-wide association studies by the support vector machine and random forest," Nucleic Acids Res., vol. 39, pp. e62-e62, 2011.

[12] W. Gronwald, M. S. Klein, R. Zeltner, B. D. Schulze, S. W. Reinhold et al., "Detection of autosomal dominant polycystic kidney disease by NMR spectroscopic fingerprinting of urine," Kidney International, vol. 79, pp. 1244-1253, 2011.

[13] A. D. Kistler, H. Mischak, D. Poster, M. Dakna, R. P. Wüthrich et al., "Identification of a unique urinary biomarker profile in patients with autosomal dominant polycystic kidney disease," Kidney International, vol. 76, pp. 89-96, 2009.

[14] A. Alkhalaf, P. Zürbig, S. J. Bakker, H. J. Bilo, M. Cerna et al., "Multicentric validation of proteomic biomarkers in urine specific for diabetic nephropathy," Plos One, vol. 5, pp. e13421-e13431, 2010.

[15] M. Haubitz, S. Wittke, E. M. Weissinger, M. Wellen, H. D. Ruppech et al., "Urine protein patterns can serve as diagnostic tools in patients with IgA nephropathy," Kidney International, vol. 67, pp. 2313-2320, 2005.

[16] S. Laufer and B. Rubinsky, "Tissue characterization with an electrical spectroscopy svm classifier," IEEE Transactions on Biomedical Engineering, vol. 56, pp. 525-528, 2009.

[17] A. Kerhet, M. Raffetto, A. Boni, and A. Massa, "A SVM-based approach to microwave breast cancer detection," Eng. Appl. Artif. Intell., vol. 19, pp. 807-818, 2006.

[18] P. K. Grewal and F. Golnaraghi, "Pilot study: Electrical impedance based tissue classification using support vector machine classifier," IET Science, Measurement & Technology, vol. 8, pp. 579-587, 2014.

[19] M. A. Shini, S. Laufer, and B. Rubinsky, "SVM for prostate cancer using electrical impedance measurements," Physiol. Meas., vol. 32, pp. 1373-1387, 2011.

[20] C. A. Gonzalez, J. A. Valencia, A. Mora, F. Gonzalez, B. Velasco et al., "Volumetric electromagnetic phase-shift spectroscopy of brain edema and hematoma," PloS One, vol. 8, pp. e63223-e63233, 2013.